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Research article

Evaluating hotspots for stormwater harvesting through participatory sensing

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ABSTRACT

Geographic Information Systems have been widely accepted to manage and manipulate spatial data associated with the hydrologic response of a watershed. Due to climate change and drought impacts, there is a need to conserve freshwater resources, which can be accomplished by introducing the concept of stormwater harvesting. Apart from hotspot identification and site screening, several economic, social, cultural, environmental aspects need to be considered before finalizing the suitable site for stormwater harvesting. The shortlisted sites are commonly ranked by considering various parameters, i.e. water demand, availability of stormwater and distance to end-use locations, which relate to economic aspects. In the present study, socio-environmental considerations are also constituted by adopting a web-GIS based approach. The geospatial datasets and metadata associated with the study area are organized as a repository in the open source database server (PostgreSQL/PostGIS), which is further assessed and analyzed by using GeoServer. This technique publishes the geospatial datasets to the public domain websites that can be accessed and visualized around the clock and across the world. This will help stakeholders gather and store responses from water planners and inhabitants, while minimizing the time and cost associated with field visits for collecting individual responses. In this respect, a questionnaire is prepared that includes queries associated with site selection and the responses are gathered from various institutions, water professionals, stakeholders and residents. Once the responses are collected, the Analytic Hierarchy Process has been implemented to compute the relative weights of each criterion with respect to the responses collected. The weights thus obtained assisted the planners in deciding the suitable stormwater harvesting site for Dehradun city in India. In context to responses gathered the sites 'B' and 'D' are given the maximum weightage to be the suitable sites in the study region. Also, the socio-environmental criteria such as 'community acceptance', 'recreational activities' and 'need for water reuse' have gathered the maximum weightage from the responses for the specific sites. Hence, the proposed methodology demonstrated how water professionals, civilians, planners, stakeholders and public can be included as participants in water-related decision making processes.

1. Introduction

Water, one of the most indispensable resources in our life, is depleting faster mainly because of the increase in population and demand (Cocos et al., 2012). Humanity is facing a major challenge to provide a reliable and affordable water supply to the increasing population while maintaining the ecological integrity of fresh water resources (Rijsberman, 2006; Ojha et al., 2008). Scarcity of water has become one of the major concerns for many states in India (Taheripour et al., 2015; Mekonnen and Hoekstra, 2016). Long-term dependency of high water demand on the limited natural water resources further aggravates this issue (Zhang et al., 2012; Wang et al., 2015). Most urban areas have limited sources of water supply owing to depleting natural aquifers, due to poor rainfall harvesting systems (Milly et al., 2005; Hoekstra and Chapagain, 2006). In order to cope with the developing populace driven demand, urban areas are confronted with the need to expand their water supply sources. This impels the urgency to reconfigure current urban water supply systems and step towards developing a more sustainable approach that includes allocation and management of water supply, wastewater resources and stormwater (Brown, 2005; Venkatesh et al., 2017; Kuriqi and Ardiçlioğlu 2018). Among several techniques, Stormwater Harvesting (SWH) is considered a preeminent option which has the potential to face both peak discharge and peak demand. The literature provides a vital proof that SWH has the best potential to reduce pressure on fresh water assets. The approaches to implement SWH at specific locations are not yet clarified as some are

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tedious and time consuming (Barkham, 1995; Atkinson et al., 2000), whereas others lack in involving vital parameters, i.e. social, cultural, environmental, habitat concerns, etc. (Pathak et al., 2017b).

Geographic Information Systems (GIS) have the ability to integrate both spatial and non-spatial attribute data, as well as to perform analysis and represent results in various formats as desired by stakeholders (Dongquan et al., 2009; Muthamilselvan et al., 2016). Various studies in the past have used remote sensing and GIS techniques for identifying hotspots in different fields (Lakshmi and Susskind, 2001; Kahinda et al., 2009; Wang et al., 2012; Singh et al., 2013; Sreedevi et al., 2013; Lakshmi, 2014; Chen et al., 2015; Kazakis et al., 2015; Akanwa et al., 2017; Pathak et al., 2017b). Once the sites are screened and finalized for SWH, the water can be stored (Szeląg et al., 2019) and purified for fulfilling the increasing portable and non-portable water demands (Kuriqi et al., 2016). GIS has the ability to incorporate data from multiple sources and generate results in various formats that helps in selection of SWH sites (Mahmoud and Tang, 2015). A GIS-based methodology was introduced to allow the swift screening of weighting of various parameters (economic factors) according to the preferences of several water professionals (Inamdar et al., 2013). Further, a robust methodology was introduced and implemented for the same purpose but without taking the opinions from water planners into account (Pathak et al., 2017b). Screening parameters such as water demand, availability of stormwater and distance to end use locations are cumulatively analyzed in shortlisting suitable sites. The parameters involved in the study relates directly or indirectly to the economic factors. In order to determine the appropriate sites for SWH, additional parameters like social, environmental, cultural, religious and habitat concerns must also be considered and analyzed. In recent decision making processes, the project demands the proper participation of the stakeholders as well as water planners along with public responses. Thus, it is essential to develop a platform that involves the participation from multiple users in enhancing decision making processes (Ryttersgaard, 2001; Janža, 2015). Recent advances in information technology include software, hardware and network offered synchronous and asynchronous communications (Zhang et al., 2007), providing a potential solution to the problem related to data accessibility and information exchange. The World Wide Web (WWW) along with software packages have provided appropriate opportunities to decision makers to involve stake holders and water professionals for an effective decision making process (Shim et al., 2002; Roppola and Bugg, 2004). The use of latest information and communication technologies assist the government to improve their planning process and provide better services to their citizens (McIvor et al., 2002; van den Berg and van Winden, 2002; Mathiyalagan et al., 2005). A new concept termed as Web-based Geographic Information Systems (Web-GIS), a hybrid of GIS and internet technologies has been introduced in past studies (Fajuyigbe et al., 2007; Blower et al., 2013). The Web-GIS framework has the potential to store and manipulate data and help users to access the information incorporated into GIS software (Wang and Wang, 2004; Shyy et al., 2007; Perovic et al., 2016; Gomariz-Castillo et al., 2017). The web provides synchronous and asynchronous platforms to achieve more participation from stakeholders and professionals by involving them in the planning process. Also, the Web-GIS facilities provide the opportunity to the distributed participants to remotely access and explore the geospatial data sets from their locations (Pettit and Nelson, 2004; Mansourian et al., 2011). Thus, web-GIS enables community-based monitoring and management, which enhances both data acquisition and public involvement in natural resources management (Angelides and Angelides, 2000; Dragicevic, 2002; Reddy and Ankaiah, 2005; Zhang et al., 2006; Gupta et al., 2010; Kanwar et al., 2010; Kleppin et al., 2010).

The applications which involve public participation and require responses for decision making, both from community and stakeholders, are referred to as ‘crowd sourcing’ or ‘participatory sensing’ (Boulos et al., 2011a; Horita et al., 2013). The use of crowd sourcing is growing rapidly because of the availability of internet-enabled and location-aware mobile devices, such as smart phones and tablets (Demirbas et al., 2010; Boulos et al., 2011b; Kanhere, 2011). Crowd sourcing is gaining popularity among institutions, companies and universities as it is a population centered modern tool for solving problems. It is mainly based upon an idea that involves an open call publication of a problem and requesting the response of the crowd for reaching the most appropriate solution (Papadopoulou and Giaoutzi, 2014). Various applications of crowd sourcing representing a robust option that facilitates the whole process are summarized in Table 1. Several mobile-based applications have been developed by applying crowd sourcing to assemble community for several public interests that require exchange of information in real time, e.g. clean streets, health coverage, drug safety

Table 1
Previous applications of web-GIS and crowdsourcing.

Author	Application of web-GIS and crowd sourcing
Stillwell et al. (1999)	Describes the role of ‘geo’ in the problems related to spatial and information
Carver (1999)	Environmental decisions
Hu (1999)	Data dissemination
Al-Kodmany (2000)	Community planning
Kingston et al. (2000)	Public participation
Angelides and Angelides (2000)	Modernizing government in planning process
McIvor et al. (2002)	Introducing transparency in public sector organizations.
Dragicevic (2002)	Environmental modelling
van den Berg and van Winden (2002)	A debate in adopting information and communication technology
Kelly and Tuxen (2003)	Environmental monitoring
Pettit and Nelson (2004)	Land management
Mathiyalagan et al. (2005)	Wetlands and agricultural ecosystems
Reddy and Ankaiah (2005)	Agricultural information dissemination to improve crop productivity
Zhang et al. (2006)	Rationalizing protected areas
Shyy et al. (2007)	Mapping aspects of quality of life
Kleppin et al. (2010)	Assessing risk in agricultural ecosystem
Gupta et al. (2010)	Planning infrastructure in rural areas
Mansourian et al. (2011)	Planning urban areas
Alikhani (2011)	Awareness against civic issues
Gao et al. (2011)	Information management system for disaster relief
Werts et al. (2012)	Soil and water conservation
Marti et al. (2012)	Noise pollution monitoring
Nedkov and Burkhard (2012)	Flood regulation ecosystem services
Zhang et al. (2013)	Natural resources management
Luan and Law (2014)	Public health surveillance system
Joost et al. (2014)	Impact of urbanization on biodiversity
Papadopoulou and Giaoutzi (2014)	Knowledge acquisition for planning applications
Maina et al. (2014)	Irrigation water management
Thombre et al. (2015)	Real time monitoring of maritime traffic
Borges et al. (2015)	Involving stakeholders in urban planning
Baker (2015)	Education and awareness
Perovic et al. (2016)	Erosion conservation practices
Juhász et al. (2016)	Inland excess water modelling
Gomariz-Castillo et al. (2017)	Estimate wind energy
Vulović et al. (2017)	Spatial data for land slides
Juma et al. (2017)	Information on Agricultural market
Haltofová (2017)	e-Government
Mauro and Lughi (2017)	Mapping land use impact of photovoltic farms
Afzalan and Sanchez (2017)	Infrastructure planning
Abubakar (2018)	Sustainable urban development planning
Wazny (2018)	Monitoring health
Perwaiz and Sinha (2018)	Assessing post disaster needs
Canli et al. (2018)	Early warning landslide system
Huang et al. (2018)	Real time flood mapping

surveillance, fire department applications, social health network, etc. These examples are freely available to the public online and demonstrate the effective and efficient use of crowd sourcing system technique in the real world.

Furthermore, in order to consider and analyze responses in a crowdsourcing based methodology, the Analytic Hierarchy Process (AHP) approach is suitable because of its capacity for strengthening the decision policy by transforming responses into relative weights. The AHP, conceived by Thomas Saaty (1980) (Saaty, 1980), is an effective tool for dealing with complex decision making problems that aids the decision maker to set priorities and opt the best decision. By reducing complex decisions to a series of pairwise comparisons and then synthesizing the results, the AHP helps capture both subjective and objective aspects of a decision. This technique considers a set of evaluation criteria and alternative options among which the best decision is to be made. It generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons. The higher the weight, the more important the corresponding criteria. In addition, it includes a measure for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process.

AHP helps determine the relative importance of a set of activities or criteria. The novel aspect and a major attribute of this approach is that it can structure any complex, multi-person, multi-criteria and multi-period problem hierarchically (Saaty, 1990). To implement this approach one has to gather the initial responses from the experts about the importance of various criteria involved in the study. The weights obtained mathematically through this approach are just a result of the responses gathered from the experts. It is also evident from the literature that, in most cases, experts and professionals are incapable of defining weights to the criteria owing to lack of data or knowledge (Mahmoud et al., 2015). Also, in recent times, governments demand more public participation in enhancing decision making processes.

In urban areas, a major problem is to locate SWH sites, considering social, technical, economic and environmental aspects of suitability. Some efforts have been made to determine techniques that are capable of shortlisting potential hotspots and then finally selecting the most suitable site by applying multi-criteria decision making analysis (Pathak et al., 2017a, b). Various approaches have been introduced that cumulatively consider all the parameters involved in shortlisting suitable sites for SWH. Conventionally, the screened sites are ranked by considering several factors, such as water demand, availability of stormwater and distance to end use locations, which are aspects directly related to economic factors. However, no approach has been proposed in the literature so far to integrate social, cultural, political, physical, environmental and habitat concerns in ranking suitable sites for SWH. This has motivated the proposal of a methodology, unified in Web-GIS architecture, which has the potential to involve public participation and provides a solution for resolving diverse aspects related to site suitability for SWH. Thus, the objectives of the study are to: i) develop a web-GIS based framework which includes thematic maps of geographical features, location of hotspots, tables describing the rankings of hotspots as obtained from previous studies, etc., ii) collect responses from experts, civilians, inhabitants on various criteria selected for site suitability and iii) analyze responses using the AHP weighing approach to rank several criteria for hotspot selection.

2. Study area

Dehradun, the capital of Uttarakhand state (India) is having a status of national importance, which justifies its selection as the study area. It is located in the Garhwal region and about 236 km north of India's capital New Delhi. It was being planned as an alternative center for growth to help ease the migration and population explosion in the Delhi metropolitan area. Dehradun is renowned for its natural resources, publishing services and for its prestigious educational institutions such as Indian Military Academy (IMA), Survey of India (SOI), Indian Institute of Petroleum, Oil and Natural Gas Corporation (CSIR-IIP), Indian Institute of Remote Sensing (IIRS), Forest Research Institute (FRI) and Wildlife Institute of India (WII). The study area is represented in Fig. 1.

It is situated in the North-West corner of the state and extends from latitude 29°58′ N to $31^0$02′30″ N and from longitude 77°34′45″ E to 78°18′30″ E. The area covered by the Dehradun district is approx. 3088 sq. km, with an average altitude of 640 m above msl. It consists of six tehsils, namely Dehradun, Chakrata, Vikasnagar, Kalsi, Tiuni and Rishikesh. There are seventeen towns and 764 villages in the district. District Dehradun is drained by Ganga, Yamuna and their tributaries. The easterly flowing rivers joins river Ganga and the westerly flowing rivers join river Yamuna. Further, the district includes the lofty peaks of the outer Himalayas as well as the Doon Valley with climatic conditions nearly similar to those in the plains. The temperature in the month of May and June is hottest with mean temperature shooting up to 36.2^0c. The city experiences the average annual rainfall of about 2050 mm per year.

Urban Dehradun is confronted with large surface runoff discharge, which results in flooded and overflow drainage lines from the influence of high intensity rainfall. Thus, it is desired to adopt some Low Impact Development (LID) techniques at SWH sites to prevent the area from over flooded streets, since the city holds the status of national importance. Eight sites were shortlisted in Dehradun city and ranked according to the various economic factors in a previous investigation (Pathak et al., 2017b). Before constructing and suggesting suitable LID practices at the top ranked sites for storing, refilling or recharging aquifers, it should be screened from various important parameters, i.e. social, cultural, political, habitat, environmental and physical factors. Fig. 1 represents the top eight sites shortlisted in urban Dehradun and the ranking of corresponding sites.

Fig. 1 represents the ranking of shortlisted sites according to the weights assigned to the parameters using the methodology discussed in the next section. ‘RI’ represents the radius of influence from the location of the SWH site to the end user. In other words, it is the physical distance from the SWH location (output) to the point of demand. The variation of these screening parameters with radial distance from each identified hotspots needs to be established as a part of relative ranking of stormwater harvesting sites.

3. Methodology

The methodology adopted in the present study incorporates the response from multiple users into the suitable site selection of SWH in urban Dehradun. The responses are analyzed and criteria are ranked using the AHP technique. In the previous study by Pathak et al. (2017b), suitable sites were identified and evaluated considering the economic aspects for SWH in Dehradun city. The data used as an input were Land Use Land Cover (LULC) map prepared at 30 m resolution, slope map prepared at 30 m resolution, soil map acquired from National Bureau of Soil Survey and Land Use Planning (NBSSLUP) and prepared at 30 m resolution and the daily rainfall data acquired from Indian Meteorological Department (IMD) at 0.25° resolution. In summary, a GIS-based screening methodology was developed and the sites were ranked according to heuristic and non-heuristic weighing approaches. The initial step in the process involved the identification and evaluation of screening parameters following four steps i.e. identification of hotspots, estimation of runoff, estimation of demand and weighted demand distance. Moreover, the parameters were normalized to a common scale and the weights were determined using the AHP, Principal Component

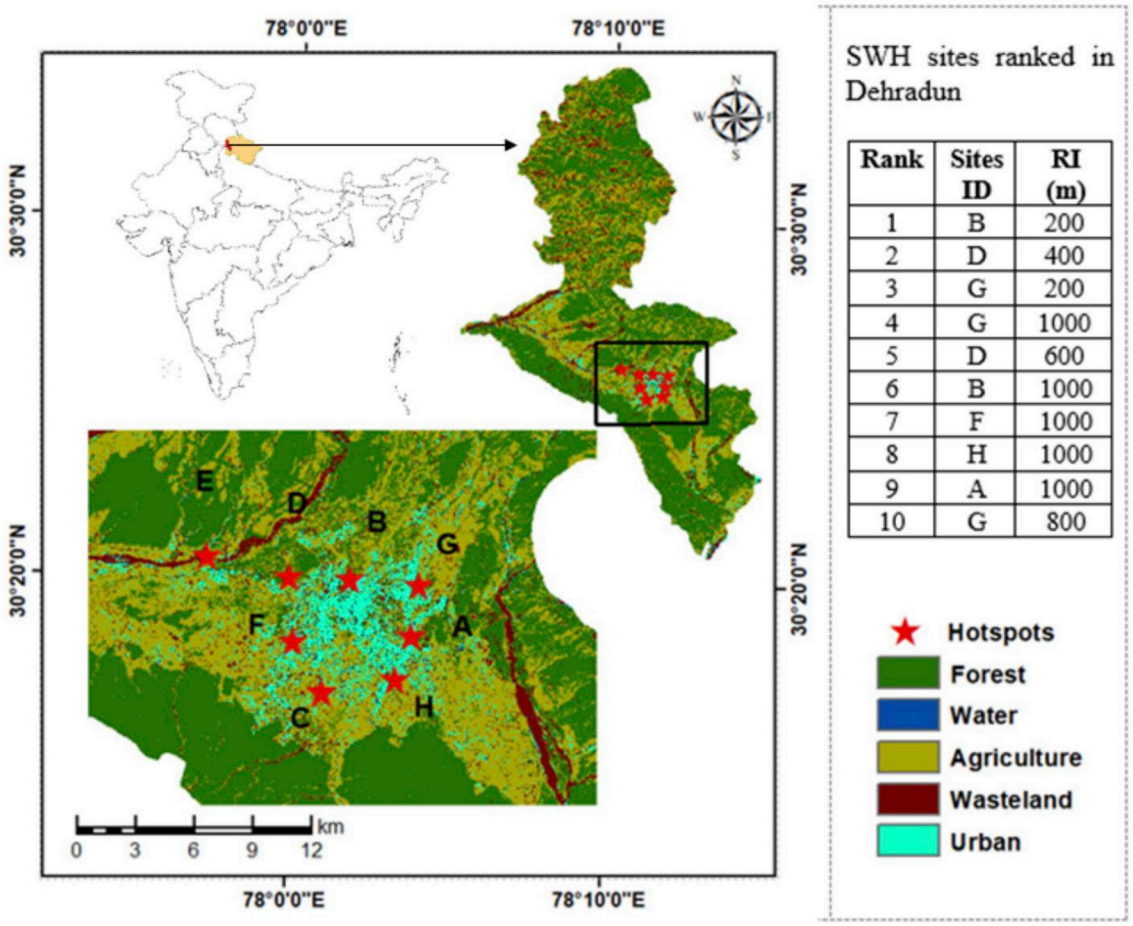

Fig. 1. Hotspots for Stormwater Harvesting in urban Dehradun (RI denotes the radius of influence) (Pathak et al., 2017b).

Analysis (PCA) and Entropy methods. Accordingly, the weights were determined and relative ranking was obtained to facilitate the decision making process.

However, the screening parameters involved in the study were directly or indirectly related to the economic factors for the ranking of SWH sites. In order to finalize the most suitable site for SWH, it is required to incorporate additional parameters that account for social, cultural, political, physical, habitat and environmental considerations.

Thus, a Web-GIS platform approach is opted to build a framework that includes features like multimedia and geovisualization tools for data representation, stakeholder elicitation, scenario planning and collaborative interaction among stakeholders and planners.

The study describes the development of a metadata catalogue framework by using GeoNetwork open source and its associated solutions. All the geospatial datasets are geographically referenced and properly organized as a repository in the dataset server for metadata editing and geovisulatization using interactive maps as represented in Fig. 2.

A web archive file of GeoNetwork open source is deployed under Apache Tomcat web server for the application configuration. It comprises McKoi SQL database server by default, but its functionality is not supportive of this application. Thus, all the geospatial datasets associated with SWH for Dehradun have been organized and stored in the PostgreSQL/PostGIS open source database server. This will help to store a large amount of data that can be accessed and manipulated at any time from this server. The open source technology plays a vital role in the development of a metadata catalogue framework. PostgreSQL is the relational database management system (RDBMS) and PostGIS spatially enables it for supporting GIS functionality. Functions associated with accessibility, sharing, editing and interoperability of geospatial datasets have been attained using GeoServer and the styling is achieved using the XML based markup language called Style Layer Descriptor (SLD). It is a Java based server working under the Apache Tomcat for controlling interoperability by using web services technology. The advantage of using GeoServer is that it provides full-fledged support for interoperability by obtaining the help from OGC specific web services, such as WFS, WMS, WPS, CSW etc.

For geovisualization and customization of SWH, geo-datasets were achieved using Javascript APIs (OpenLayers, GeoExt and ExtJS) for web browser environment. XML and XSLT have been used for transferring metadata and interactive Graphical user interface (GUI). Apache Tomcat hypertext transfer protocol (HTTP) server provides a platform to deliver web content through the internet. The web server supports and display web pages to the clients through HTTP, which is the medium for interaction between server and client. The methodology adopted is represented in Fig. 3.

Furthermore, in order to gather response from various institutions, community and stakeholders, a response questionnaire has been conceived that incorporates all queries regarding the social, cultural, physical, habitat and environmental impacts of SWH sites as shown in Fig. 5. This will help water professionals to strengthen their planning processes. In order to include more opinions in the decision making, a small workshop was organized in the institute. Experts from various

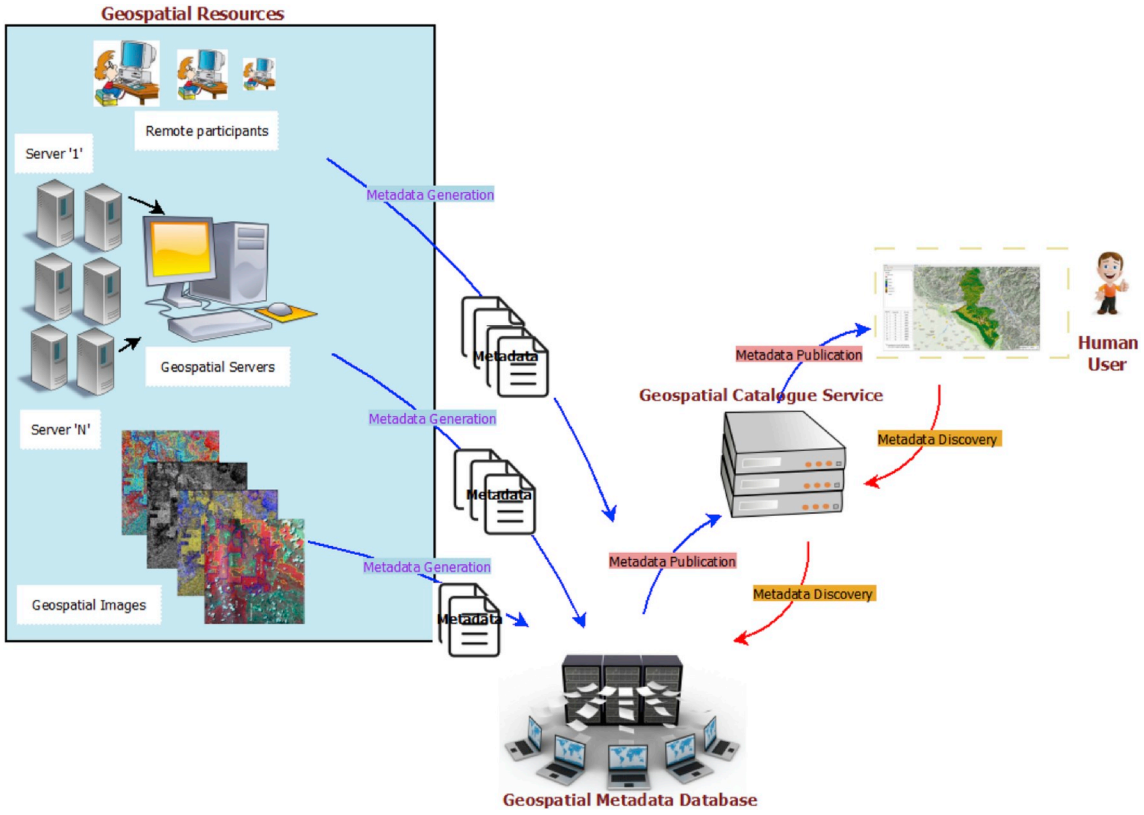

Fig. 2. General architecture for the Metadata Cataloging framework.

fields, viz. public health department, an environmentalist, a post graduate in advanced construction management, a non-government organization (NGO) activist and an executive engineer from irrigation department (Dehradun) were requested to attend this workshop. The attendees were given a brief introduction about various shortlisted sites, their location, water demand, available runoff and the methodology that is adopted for selecting SWH sites. The participants in the workshop were mostly post grads and graduates; however, the questionnaire designed in the study does not require the participant to have technical background in order to respond to the criteria. After providing a brief explanation on various aspects associated with SWH, the attendees were asked to amiably provide the responses for different selection criteria which are further analyzed through the AHP approach. Hence, the response weights (RW) gathered from various responders are transformed into AHP weights.

The range of 'RW' is from 1 to 5, whilst that of the AHP method is from 1 to 9. Thus, to transform RW into AHP weights, two most consecutive weights are considered. It means that if the maximum RW for any criteria is 3 followed by second maximum is 4, then the AHP weight allotted is 6 and similarly, if the maximum RW of any criteria is 3 followed by second maximum is 2, then the AHP weight allotted is 5. Similar approach is adopted for other criteria as well, as represented in Table 2.

Thus, the vector of criteria weights is computed as follows:

a) Creating a pairwise comparison matrix A.

A = m*m matrix; m = evaluation criteria; each entry a_{jk} represents the importance of jth criteria with respect to kth criteria. The relative importance between two criteria is measured according to a numerical scale from 1 to 9 as shown in Table 2.

b) Once the matrix A is built, it is possible to derive the normalized pairwise comparison matrix A_{norm} from A by making the sum of the entries on each column equal to 1, i.e. each entry a'_{jk} of the matrix A_{norm} is computed as

$$a'_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \tag{1}$$

c) Finally, the criteria weight vector w, which is an m-dimensional column vector, is built by averaging the entries on each row of A_{norm}, i.e.

$$w_j = \frac{\sum_{l=1}^{m} a'_{jl}}{m} \tag{2}$$

The accuracy of pairwise comparison is assessed through the computation of consistency index (CI), which measures the departure from consistency based on the comparison matrices. CI determines the inconsistencies in the pairwise judgements, and allows the planners for re-evaluation of comparisons. The CI is expressed as

$$CI = \frac{\lambda - n}{n - 1} \tag{3}$$

where λ is the mean value of the consistency vector and n is the number of columns in the matrix (Saaty, 1990; Vahidnia et al., 2008; Garfi et al., 2009). The consistency ratio is then calculated as

$$CR = \frac{CI}{Ri} \tag{4}$$

where R_i is the random index, which depends on the number of elements being compared (Saaty, 1977).

4. Results

SWH sites-related datasets for Dehradun city, such as Digital

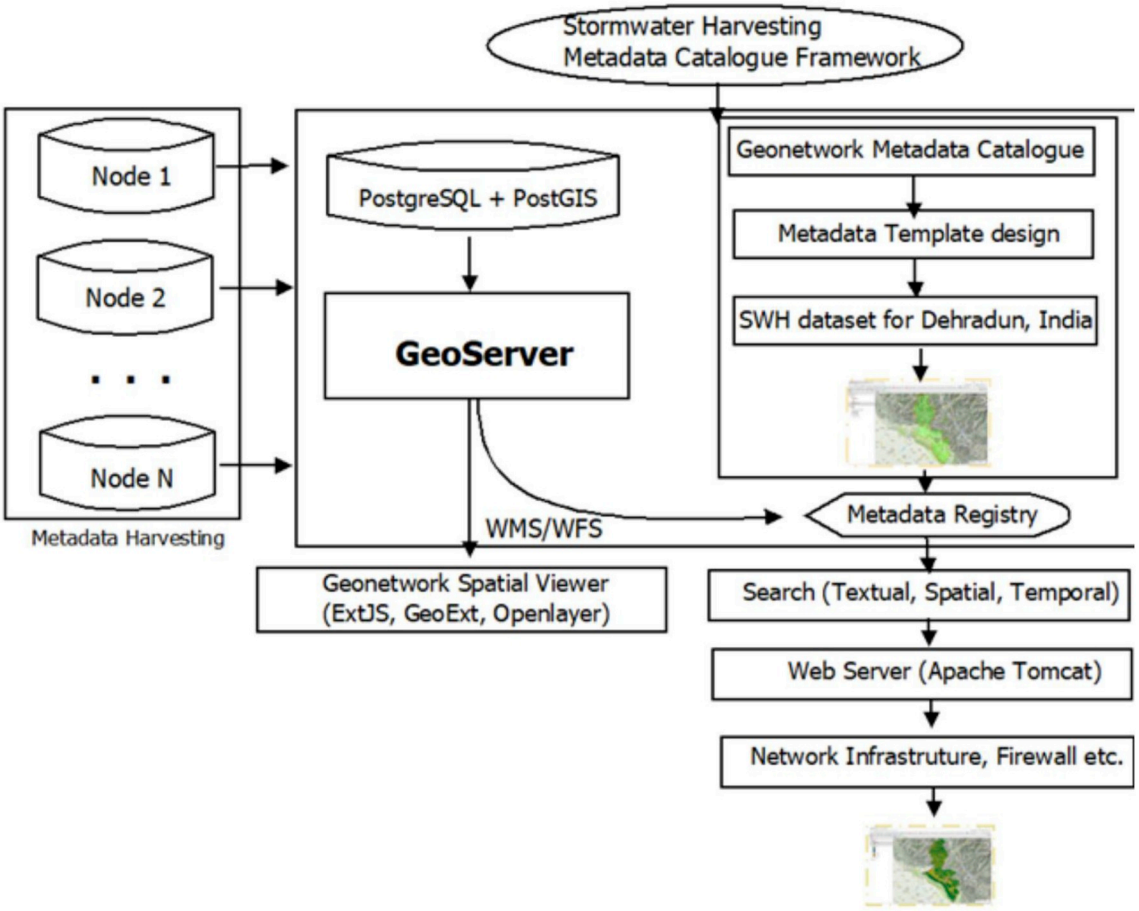

Fig. 3. System structure to publish geospatial dataset to web.

Table 2
AHP weights assigned according to response weights from crowdsourcing.

AHP Weight	Weight Assigned According To Response Weight (RW)
1	Maximum RW is 1
2	Maximum RW is 1 followed by 2
3	Maximum RW is 2 followed by 1
4	Maximum RW is 2 followed by 3
5	Maximum RW is 3 followed by 2
6	Maximum RW is 3 followed by 4
7	Maximum RW is 4 followed by 3
8	Maximum RW is 4 followed by 5
9	Maximum RW is 5

Elevation Model (DEM) acquired from the SRTM at 30 m resolution, LULC map prepared from Landsat 8 at 30 m resolution, slope map prepared from DEM, population acquired from Dehradun census data, shortlisted sites obtained from previous investigation (Pathak et al., 2017a, b), soil map acquired from NBSSLUP, etc., are organized as a metadata catalogue in the PostgreSQL/PostGIS database server. The geospatial dataset of the resulting shapefile and hotspots along with the table, representing the ranking of the sites for urban Dehradun, is depicted in Fig. 4.

The graphical user interface of the map viewer has been customized using JavaScript APIs (GeoExt, OpenLayers and ExtJS). All the associated geospatial datasets are organized in the open source database server and published using GeoServer. The styling is performed in GeoServer using a XML-based markup language called Style Layer Descriptor (SLD).

To evaluate the additional parameters associated with the site selection process and finalizing a suitable site for SWH, a questionnaire (Fig. 5, Appendix A) has been prepared that involves public participation including social, cultural, political, habitat, physical and environmental aspects.

Furthermore, the attendees were asked to faithfully respond to various queries (Fig. 5, Appendix A). The responses from various institutions, water professionals, planners, health departments and the inhabitants are stored in a database which can be later viewed as an individual response or as a summary as shown in Fig. 6, Appendix A. Thus, a total of 82 responses were gathered from various institutions, civilians and professionals in water planning and public health and stored in the database. The most desired sites selected were ‘B’ and ‘D’. Public health risk, impact on environment, construction risks and effect on nearby habitat were given a weightage between 2 and 3. This represents that the introduction of SWH sites at ‘B’ and ‘D’ will have low impact on these parameters. For the parameters needed for recreational activities, community acceptance and need for water reuse, the weightage allotted by the responders was in between 4 and 5. This indicates the acceptance of the community in introducing SWH structures at site ‘B’ and ‘D’. As for other three parameters, namely condition of groundwater and effect on nearby cultural and religious heritage, the maximum weights assigned by the responders were 3. This means that the community was neither in favor nor against these parameters at the particular sites. Furthermore, the rankings can be amended by spreading awareness about SWH and water reuse among civilians and

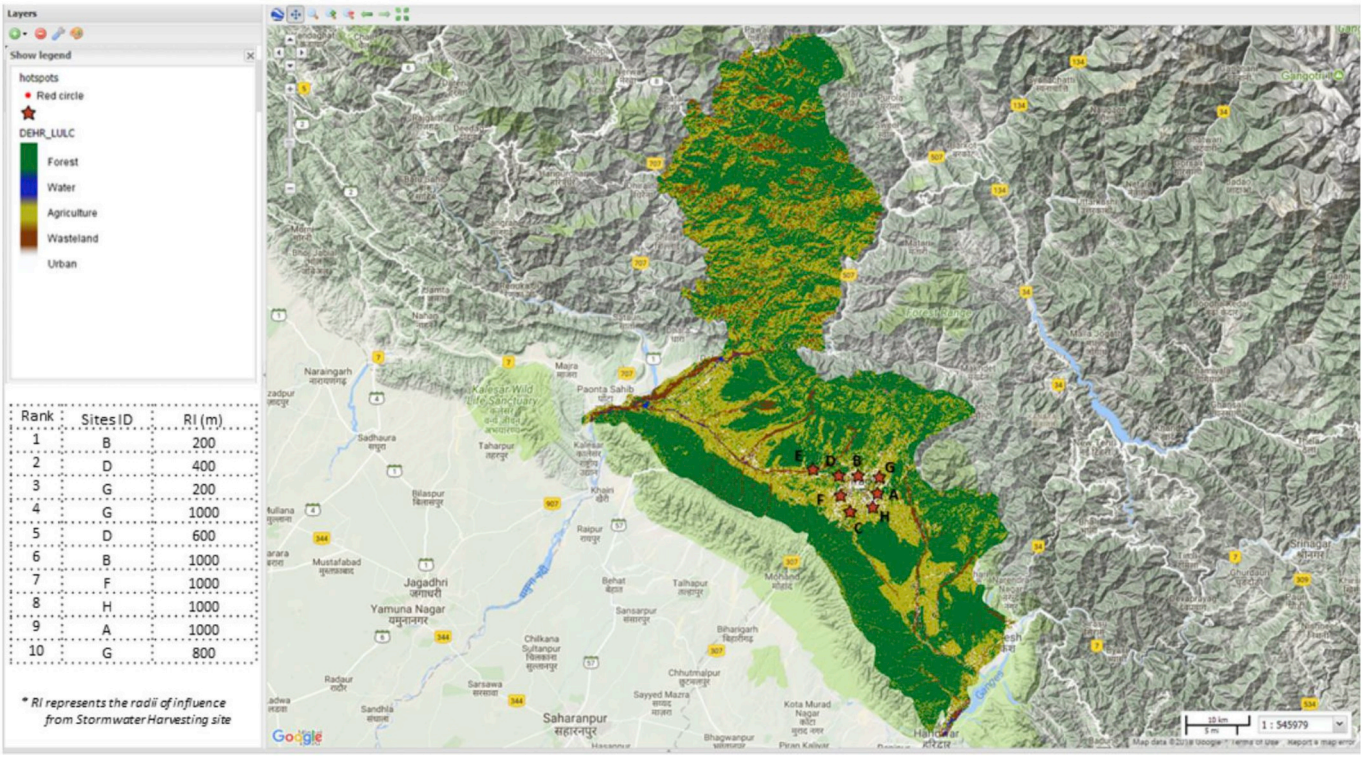

Fig. 4. Representation of geospatial dataset for Dehradun district through HTTP.

Table 3
AHP weights assigned to different criteria.

Questions	Response weights	AHP weights
Public Health Risk (PHR)	2 followed by 3	4
Impact on Environment (IR)	3 followed by 2	5
Construction Risks (CR)	3 followed by 2	5
Need for Recreational activities (NRA)	4 followed by 5	8
Community acceptance (CA)	4 followed by 3	7
Need for Water Reuse (NWR)	5	9
Effect on nearby cultural heritage (ECH)	3 followed by 2	5
Effect on nearby religious heritage (ERH)	3 followed by 4	6
Condition of Groundwater (CG)	3 followed by 2	5
Effect on Nearby habitats (ENH)	3 followed by 2	5

residents. This technique provides a brief assessment on the requirements and the demand of the public regarding the introduction of SWH sites at specific locations.

The responses obtained for all the 10 criteria are evaluated and analyzed. The values of RW are converted to AHP weights as shown in Table 3, indicating the mathematical representation of the 82 responses gathered. To analyze these weights, the comparison matrix is prepared for various criteria. The relative weights are obtained from the comparison matrix for all the 10 criteria as shown in Table 4.

In addition, the consistency ratio (CR) is computed to check the accuracy of the above generated matrix. The CR of the matrix is an indicative of the level of consistency achieved, compared with that of the generated matrix. For the present study, Ri is 1.49 (Saaty, 1990) and the CR obtained is 0.0, which is inferior to 0.10 (Saaty, 1977). Henceforth, the rating is deemed to have an acceptable consistency. It has been observed that some of the parameters, viz. 'Impact on Environment', 'Construction Risks', 'Effect on nearby cultural heritage', 'Condition of Groundwater' and 'Effect on Nearby habitats' have received equal weightages (0.085). The parameter 'Need for Water Reuse' has received the maximum weightage (0.153), followed by 'Need for Recreational activities' (0.136) and 'Community acceptance' (0.119). Finally, the parameter 'Public Health Risk' has received the minimum

Table 4
AHP pairwise comparison matrix of criteria with relative weights.

Criteria's	PHR	IR	CR	NRA	CA	NWR	ECH	ERH	CG	ENH	weight
Public Health Risk (PHR)	1	4/5	4/5	4/8	4/7	4/9	4/5	4/6	4/5	4/5	**0.068**
Impact on Environment (IE)	5/4	1	5/5	5/8	5/7	5/9	5/5	5/6	5/5	5/5	**0.085**
Construction Risks (CR)	5/4	5/5	1	5/8	5/7	5/9	5/5	5/6	5/5	5/5	**0.085**
Need for Recreational activities (NRA)	8/4	8/5	8/5	1	8/7	8/9	8/5	8/6	8/5	8/5	**0.136**
Community acceptance (CA)	7/4	7/5	7/5	7/8	1	7/9	7/5	7/6	7/5	7/5	**0.119**
Need for Water Reuse (NWR)	9/4	9/5	9/5	9/8	9/7	1	9/5	9/6	9/5	9/5	**0.153**
Effect on nearby cultural heritage (ECH)	5/4	5/5	5/5	5/8	5/7	5/9	1	5/6	5/5	5/5	**0.085**
Effect on nearby religious heritage (ERH)	6/4	6/5	6/5	6/8	6/7	6/9	6/5	1	6/5	6/5	**0.102**
Condition of Groundwater (CG)	5/4	5/5	5/5	5/8	5/7	5/9	5/5	5/6	1	5/5	**0.085**
Effect on Nearby habitats (ENH)	5/4	5/5	5/5	5/8	5/7	5/9	5/5	5/6	5/5	1	**0.085**

weight (0.068).

5. Discussion

During the implementation of the proposed framework, digital maps were prepared and uploaded on the website so that the decision can be made around the clock. This approach is very effective for the participants to respond swiftly. The use of geospatial datasets in representing the data in a map interface and multimedia content, makes the structure more attractive and involves participation more actively, thus enhancing the decision making process.

The study demonstrates the potential and benefits of integrating GIS with web technology. The Web-GIS platform developed for the study helps the water planners to bring all decision makers under one roof and reach at one specific decision. It provides suitable information in selecting appropriate SWH sites and offers multi-objective evaluation of the sites under diverse views from various planners. Earlier studies related to site suitability considered economic aspects or the criteria related to landscape of the region because that can be quantified and analyzed. However, equally important criteria such as social, cultural, political, physical, environmental, habitat concerns, etc., were missing in the site suitability studies because of the difficulty in analyzing the opinions. Also, in some scientific research, the expert opinions are promoted and based on their decision, the sites are finalized which inherent subjectivity in the approach. Thus, the study removes the subjectivity from the methodology to identify site suitability as well as includes simultaneous responses from public and stakeholders in the decision making process. To obtain this objective, the Web-GIS framework were developed and the responses were gathered from the institutions and the stakeholders. The total of 82 responses were collected and analyzed using saaty AHP approach. The responders were asked to weigh the criteria on the scale of 1–5. In Fig. 6, Appendix A, the responses can be observed and analyzed as an individual or cumulatively. Further, to analyze the responses, the scale was transformed to saaty scale of 1–9 as described in the methodology. Once the scale is transformed, the comparison matrix was formed as represented in Table 4 and the consistency ratio was computed to check the consistency of comparison matrix. According to Fig. 6, Appendix A, out of eight shortlisted sites, two sites i.e. ‘B’ and ‘D’ were given maximum weight and consent for recommending the stormwater harvesting sites. In context of the socio-environmental criteria, the criteria community acceptance, recreational activities and the need for water reuse have allotted the maximum weighs by the responders. Thus, the results obtained are site specific and totally depends upon the inhabitants and expert opinions. Also, by saaty AHP approach the qualitative analysis of socio-environmental aspects are transformed to quantitative aspects and analyzed by obtaining the comparison matrix as represent in Table 4. Thus, the responses are represented by mathematical value which helps in understanding the relative importance of each criterion. Subsequently, the most important sites are finalized for implementing the SWH schemes by considering the multi-objective decision making approach for the study.

Furthermore, the findings of the present study may not be compared with any of the previous study employed for hotspot identification and selection because (a) In the previous studies the methodology adopted by the scientific community to select suitable sites (for SWH, dumping wastes, identifying hotspots for certain projects, etc.) only consider economic criteria. The 10 criteria that are analyzed in the present study are non-economic factors and consider social aspects; (b) It has been noted in previous studies that in order to assign weights to the criteria the stakeholders have to concern water planner which introduces subjectivity in the approach. However, recent studies claim that most of the time experts are incapable of defining weights to the criteria owing to lack of data or knowledge (Mahmoud et al., 2015). Also, recent government demands public participation in decision making process. Thus, to incorporate broader prospective, the responses from multiple experts including civilians, inhabitants, professionals, etc., are collected through web-GIS to obtain relative weights for each criterion. Since the criteria involved in the present study are site-specific and no past study has utilized these parameters in this study region, the outcomes of this investigation cannot be compared with any previous work; (c) Although Table 1 describes multiple examples where web-GIS and crowdsourcing have been used for public participation for decision making in different fields, the criteria they used are completely different from those considered in this study, which makes the comparative analysis of their outcomes impossible.

6. Conclusions

Planning in the real world is a complex and multidimensional process that requires modification of the traditional approaches. The need from multiple and interactive water planners for addressing the dubious nature of the external environment can be accomplished using Web-GIS spatial database frameworks. This framework will facilitate stakeholders and water professionals by integrating distributed, collaborative and continual planning mechanisms and thus structuring the resulting planning process to web. The dual information flow feature between the users and planners allows the real time interactions and speed up the planning process. A benefit using Web-GIS is that the decisions are anchored around the map and opinions are recorded in the real time. The literature shows a wide variety of countless examples where the decision requires an effective way of communication between scientists, citizens, stakeholders and decision makers. Citizens must be involved in the decision making process, since the advancements in computer technologies and the internet have provided sophisticated tools that can help in information gathering, storing and transmission. To this end, Web-GIS has come out to be a great technology that has the ability to represent geospatial datasets associated with any decision process in a very organized and interactive way.

The study implemented Web-GIS platform to interact with civilians and experts, who further assist stakeholders in enhancing decision making processes. Also, the response weights were processed using the AHP method. This helps the planners to analyze which criteria are most suitable for specific study areas. To maintain the integrity in the responses, the civilians were briefed about the various strategies and methodology implemented to shortlist potential sites and defining various social aspects considered in the study. However, if this approach is implemented solely through participatory sensing, the uncivilized community would have faced it difficult to respond to these queries without understanding its individual importance. The results clearly portraits the importance of various social aspects related to site selection for the urban Dehradun however, the same weights cannot be utilized for the other study area as they are site specific and will depends upon the local opinions. Henceforth, for the future study it is recommended to vigorously explore the functionalities and application of Web-GIS so that a robust framework can be created to provide a platform for communication, data interaction and decision making between water planners and stakeholders, in order to promote public participation.

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Appendix A

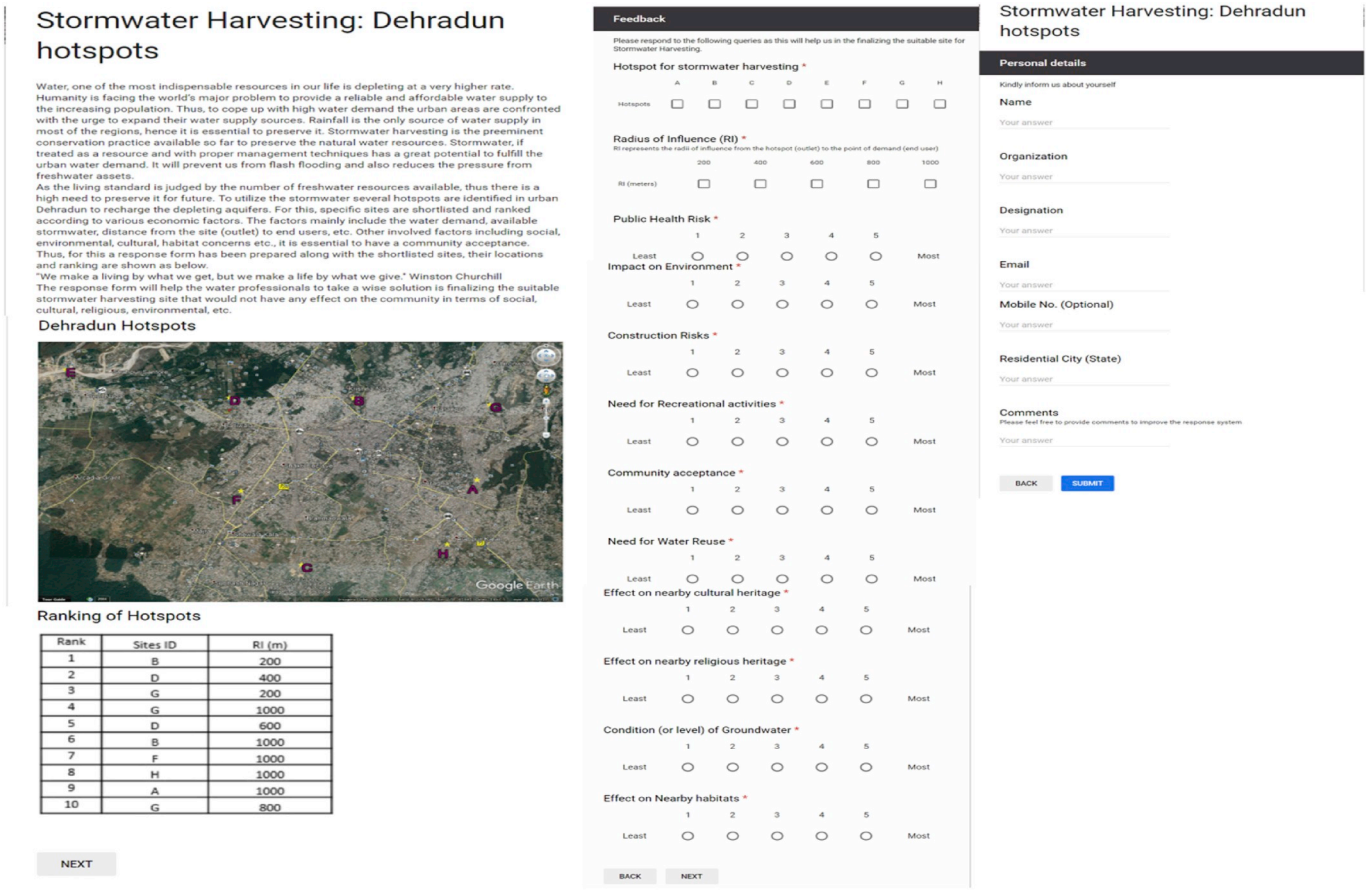
Stormwater Harvesting: Dehradun hotspots
Water, one of the most indispensable resources in our life is depleting at a very higher rate. Humanity is facing the world's major problem to provide a reliable and affordable water supply to the increasing population. Thus, to cope up with high water demand the urban areas are confronted with the urge to expand their water supply sources. Rainfall is the only source of water supply in most of the regions, hence it is essential to preserve it. Stormwater harvesting is the preeminent conservation practice available so far to preserve the natural water resources. Stormwater, if treated as a resource and with proper management techniques has a great potential to fulfill the urban water demand. It will prevent us from flash flooding and also reduces the pressure from freshwater assets.
As the living standard is judged by the number of freshwater resources available, thus there is a high need to preserve it for future. To utilize the stormwater several hotspots are identified in urban Dehradun to recharge the depleting aquifers. For this, specific sites are shortlisted and ranked according to various economic factors. The factors mainly include the water demand, available stormwater, distance from the site (outlet) to end users, etc. Other involved factors including social, environmental, cultural, habitat concerns etc., it is essential to have a community acceptance. Thus, for this a response form has been prepared along with the shortlisted sites, their locations and ranking are shown as below.
"We make a living by what we get, but we make a life by what we give." Winston Churchill
The response form will help the water professionals to take a wise solution is finalizing the suitable stormwater harvesting site that would not have any effect on the community in terms of social, cultural, religious, environmental, etc.
Dehradun Hotspots
Google Earth
Ranking of Hotspots
Rank | Sites ID | RI (m)
1 | B | 200
2 | D | 400
3 | G | 200
4 | G | 1000
5 | D | 600
6 | B | 1000
7 | F | 1000
8 | H | 1000
9 | A | 1000
10 | G | 800
NEXT
Feedback
Please respond to the following queries as this will help us in the finalizing the suitable site for Stormwater Harvesting.
Hotspot for stormwater harvesting *
Hotspots
Radius of Influence (RI) *
RI represents the radii of influence from the hotspot (outlet) to the point of demand (end user)
RI (meters)
Public Health Risk *
Impact on Environment *
Construction Risks *
Need for Recreational activities *
Community acceptance *
Need for Water Reuse *
Effect on nearby cultural heritage *
Effect on nearby religious heritage *
Condition (or level) of Groundwater *
Effect on Nearby habitats *
Least
Most
BACK
NEXT
Stormwater Harvesting: Dehradun hotspots
Personal details
Kindly inform us about yourself
Name
Organization
Designation
Email
Mobile No. (Optional)
Residential City (State)
Comments
Please feel free to provide comments to improve the response system
Your answer
BACK
SUBMIT

Fig. 5. Questionnaire to involve public participation for decision making for SWH.

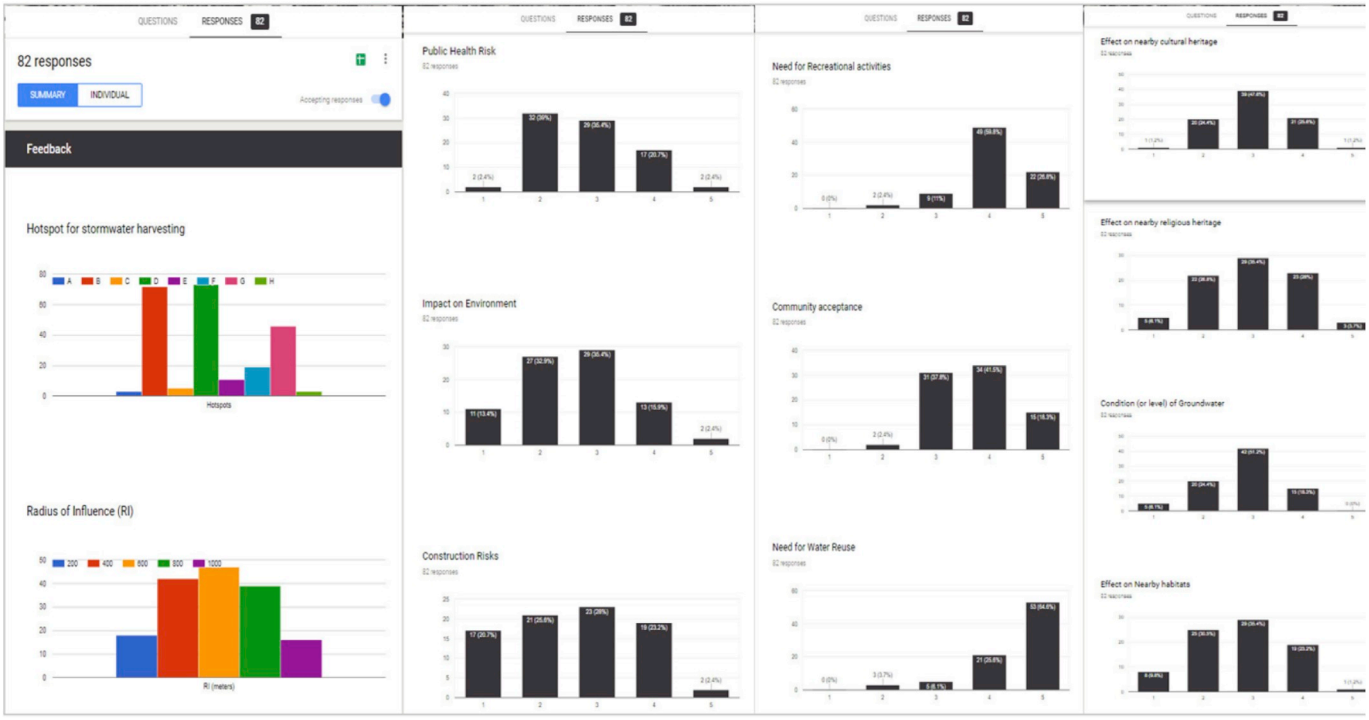

Fig. 6. Representation of responses gather from various institutions.

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